Microstructural evolution and mechanical properties of LM6 Al alloy

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ABSTRACT

In this paper, multi-axial compression of LM6 Al alloy were performed at room temperature using strain of 0.2 in each pass. Total cumulative strains 0.6, 1.2 and 1.8, were applied in three, six and nine passes, respectively. Microstructural evolution is studied using light optical microscopy of the compressed specimen. Properties (tensile strength, hardness, toughness) of deformed specimens were studied using tensile and hardness tests, and relate them with their microstructures and fractographs. As passes increased from zero to nine, 62% of tensile strength of the material is increased along with hardness from 52 VHN to 74VHN.

Keyword: Multi-axial compression, Hardness, Tensile test, Optical microscopy, Fractograph.

INTRODUCTION

In development of high strength components/products, grain refinement plays a vital role in manufacturing industries. Grain refinement affects mechanical properties of the material with or without use of temperature. Now a day's grain refinement has become one of the most suitable technique in materials development. Grain refinement can be produced by two different ways i.e., bottom-up approach, and top-down approach. In bottom-up approach refers to develop a material from smallest element i.e., atom and then move toward bigger one i.e., cluster. Inert gas condensation, electro deposition, ball milling with subsequent coalition and cryo-milling are the examples of this technique. In top-down approach severe plastic deformation (SPD) of coarse-grained polycrystalline materials is introduce by mechanical process to improve dislocation density without any contamination. In general, this approach refers to the continuous processing of a bulk material to generate nano-size structured material. Components produced using bottom-up approach have higher strength as compare to that of top-down approach, but it has more drawbacks viz. low ductility, weak bonding between particles. Also, this approach is only suitable for production of exceptionally very small components and they are not amenable for use in large scale structural applications (Langdon et al., 2003 & Kodak et al., 2011).

Aluminum has wide applications in industries because of being high in strength to weight ratio with adequate ductility and toughness. LM6 is two phase aluminum alloy having major alloying element silicon. LM6 Al alloy is fourth series aluminum alloy having approximately 10-13 % by weight silicon, and about 1-2% by weight other elements i.e., Cu, Ti, Fe, and Zn etc. with 86-90% aluminum. It is generally used in marine industry, automobile and road transport fittings, meter cases and switch boxes, water cooled manifolds and jackets etc. Binary eutectic Al-Si alloys such as LM6 have a high corrosion resistant, standard durability, high impact strength and ductility. Al-Si alloys are relatively lighter than pure Al and expresses good castability, wear and corrosion resistance. Because of being casted in nature, the grain refinement of LM6 aluminum alloy reduces the defects which were produced during casting of alloy, and improves the quality of the material. Grain refinement reduces α-Al grains and produced fine equiaxed grain structure, leads to numerous benefits (Pio et al., 2005). Their behaviour with heat treatment remains partial to structural adaptation of eutectic Si particles. LM6 Al alloy is cheaper than other Al-Si alloys. Addition of Si improves casting characteristics of Al alloy. Silicon also makes more positive to electrolytic potential in solution, resulted enhancement in corrosion resistance. The high hardness of Si particles promulgates wear resistance to Al and delivered the ability to Al-Si alloys to resist inter-crystalline strike in rural, industrial and marine industries (Gupta et al., 2012).

Grain size reduction plays a very vital role in enhancement of properties of a polycrystalline material (Rajput et al., 2020 & Rajput et al., 2020). Low strength of commercial pure aluminium can be improved by work hardening and grain size reduction (De Faria et al., 2016). SPD has widely used to reduce the grain size from micrometre to sub-micrometre or nanometre (Zrnik et al., 2016). Deformation to large strains is a route cause for producing ultrafine-grained structures exhibits high strength (Doppalapudi et al., 2010, Fritsch et al., 2012, Kransnoveikin et al., 2017, Liu et al., 2011, Mehta et al., 2018, Cardoso et al., 2011, Furukawa et al., 2002 & Valiev., 2004). It is one of the most suitable metal forming process which induces large number of dislocations in the material results refined material. It involved a complex state of stress, resulted high defect density and equiaxed ultrafine grains. Fine grained materials possess good strength for production of consumer safe and reliable products. SPD enhanced the mechanical properties of the material without large loss of ductility, results better performance of the material. Plastic deformation produces shear bands which plays a considerable role in grain refinement (Tanski et al., 2017). Local dynamic recovery and recrystallization are responsible for grain refinement. Large amount of distortion approaches to a discrete structure of dislocation-free and highly misoriented fine-grained material (Zehetbauer et al., 2010). As the number of passes increases, grain size of the material become refine, responsible to increase mechanical properties of high P steel (Katiyar et al., 2017).

Although there are number of literatures in multiaxial deformation of different alloys but there was scarcity of literatures in multi-axial deformation of LM6 Al alloy. Thus, there is need to systematic study of evolution of microstructure after multiaxial deformation. In this work, multi-axial compressions of LM6 Al alloy were performed at room temperature, and the evolution of microstructures and mechanical properties were studied. Also, relate the mechanical properties with corresponding microstructures.

EXPERIMENTAL METHODOLOGY

Procured material (LM6 Al alloy) in the form of a bar was analysed using spectroscopy analysis technique to determine chemical composition (wt. %) (Table 1).

Table 1 Chemical composition of LM6 Al alloy (wt. %).

Elements	Cu	Si	Ti	Zn	Fe	Al
Wt. %	0.015	11.32	0.009	0.074	0.459	Bal.

Specimens were cut in tha ratio of 1.227:1.13:1 for MAC operation having dimensions of 20.5mm×19.0 mm×16.7 mm, and the dimensional ratios are same during whole multi-axial compressions operation (Rao et al., 2013). Specimens were compressed upto true strain of 0.2 in each step at room temperature, and the cummulative true strain were 0.6 for one cycle (3 pass). The specimens were compressed upto true strains of 0.6, 1.2 and 1.8, followed by in-situ water quenched the specimens to preserve the microstrures. For microstructural study, the compressed specimens were cut along the compression direction, and polished with polishing paper and double disk polishing machine. Keller's reagent was applied to etch specimens and light optical microscope (Leica DMIL M LED) was used to capture the microstructures. To determine the hardness Vickers hardness testing machine was used. In order to determine the tensile strength, tensile tests were conducted using screw driven UTM (Instron-1195) at room temperature. Fractographs of the fractured specimens were observed using SEM (Carl Zeiss EVO 50).

RESULTS AND DISCUSSION

Microstrcture of as-received specimen of LM6 Al alloy showed coarser grain with porosity and large chain of precipitate dendrites (white color) (Figure 1a). Generally, dendrites are formed during the casting of aluminium alloys when equlibrium temperature was not maintained. Less dendritic structure showed higher mechanical property of the material. More dentritic structure can be a primary cause of reduction in mechanical properties of material, and cracks can be developed during initial compression work. However, if the cooling rate is high enough dendrite growth could be strangled due to large undercooling of the molten metal, results amorphous material. Generally, there are two types of dendrites precipitates available in LM6 Al alloy i.e., α-Al dendrites and β-Al dendrites. Studied material has only α-Al dendrites because of absence of magnesium (Hyde et al., 2007).

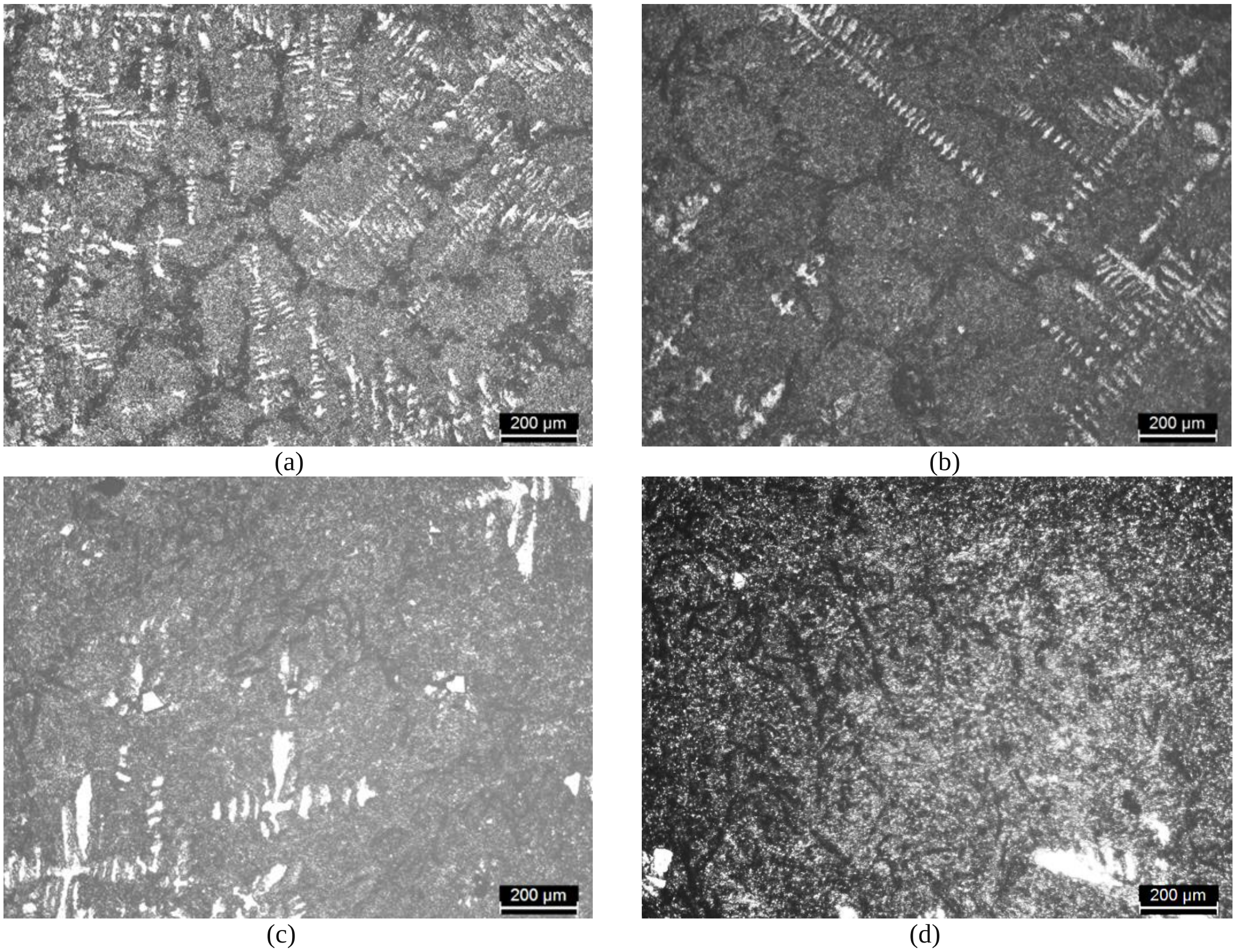

Figure 1 Optical micrographs of (a) as received, (b) three pass, (c) six pass, and (d) nine pass.

Figure 1b shows the micrograph of three pass specimen (one cycle) with cumulative strain upto 0.6. Microstrure shows the reduced grain size (a little change in grain size was observed as compared to as-received specimen) with less amount (huge reduction in dendrites) of dendritic structure as compared to that of as-received material. It showed that there is some increment in the mechanical properties. Fine structure was developed due to less dendrites. Further increase in cumulative strain upto 1.2 (six pass) showed less formation of tree like structure means reduction in precipitate dendrites (Figure 1c). When the specimen was further compressed up to cumulative strain of 1.8 (nine pass), very fine grained structure with little amount of dendrites were observed as shown in Figure 1d. Further deformation of specimens was not possible due to formation of cracks.

Figure 2 represents the stress-strain curve of as-received and deformed specimens. It is clearly visible from stress-strain diagram that ultimate tensile strength of the three, six and nine pass specimens has much more than that of as-received specimen. Ultimate tensile strength of the as-received, three, six, and nine passes, are 167 MPa, 213 MPa, 247 MPa, and 270 MPa, respectively. This shows that multi-axial compression is responsible for grain refinements, resulted enhancement of tensile strength with increase in pass. About 62% increment of tensile strength was observed as the deformation increased from zero pass to nine passes.

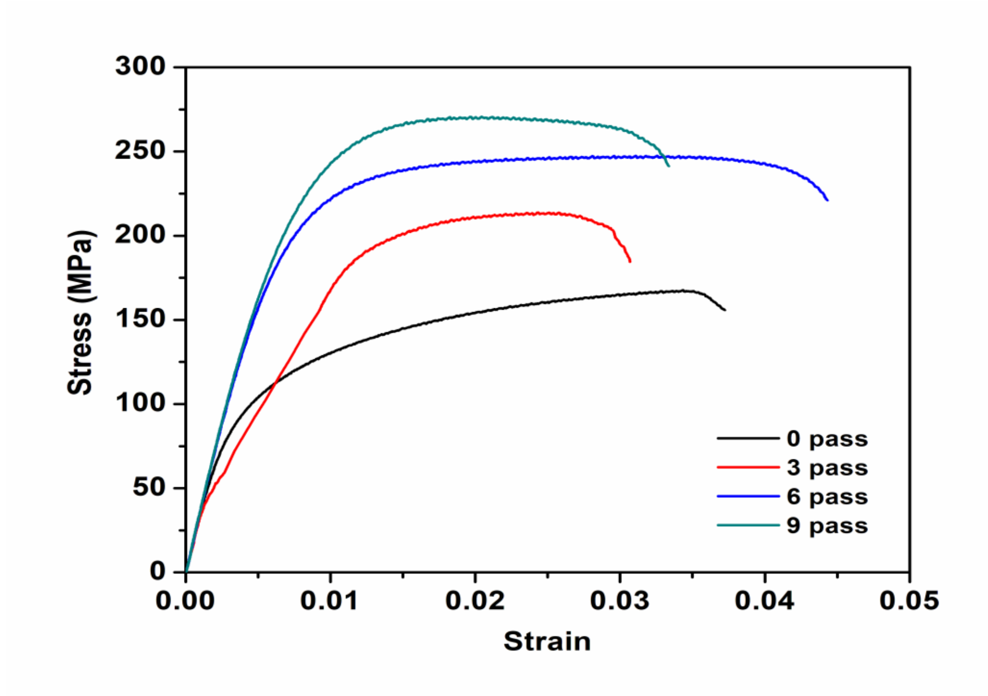

Figure 2 Stress strain curve of as-received and deformed specimens of LM6 Al alloy.

Figure 3 shows the variation of toughness with further increment in number of passes. In comparison to as-received specimen, some reduction in toughness was observed in three pass specimens. Further, deformation shows good increment in toughness upto six pass and after that it decreased to some extent. The loss of toughness of material is due to the loss of strain hardening capability, and the progress of local plastic instabilities (Hahn et al. 1975).

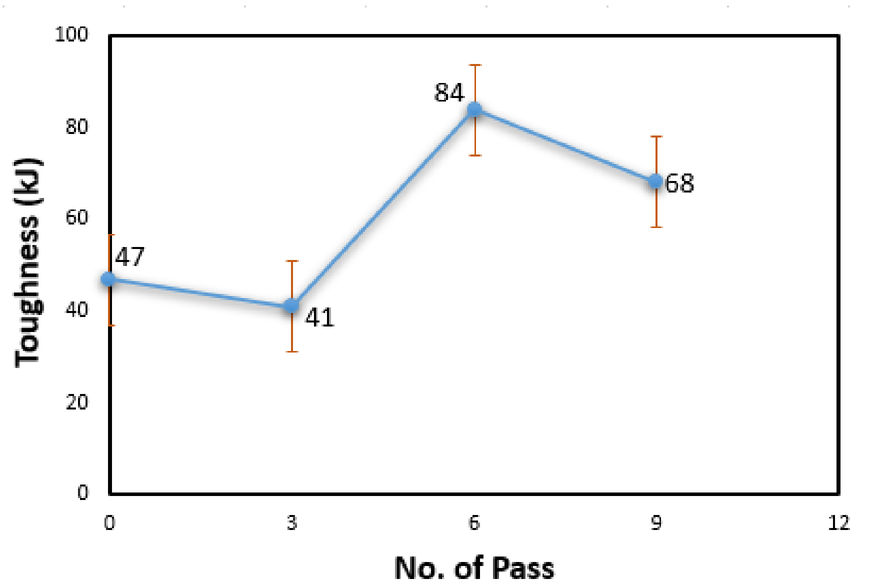

Figure 3 Variation of toughness (kJ) with number of passes of deformation in LM6 Al alloy.

Plastic deformation of material is mainly dependent on materials ductility, since ductility of material is the measure of ability to undergo considerable plastic deformation before fracture, and can be illustrated as percentage elongation or percentage area reduction. The total percentage elongation is about 72 %.

Figure 4 shows the fractographs of tensile fractured specimens. Rough fracture with large size of dimples was observed (Figure 4a) that depicts fracture is fully ductile in nature. As the number of passes increased, the size of dimples was reduced and becomes smaller as compare to that of zero pass specimens as shown in Figure 4b, c, and d. Fine grained structure reduces the ductility of material resulted reduction in toughness. Large amount of energy is required to fracture the material having high density of dimples.

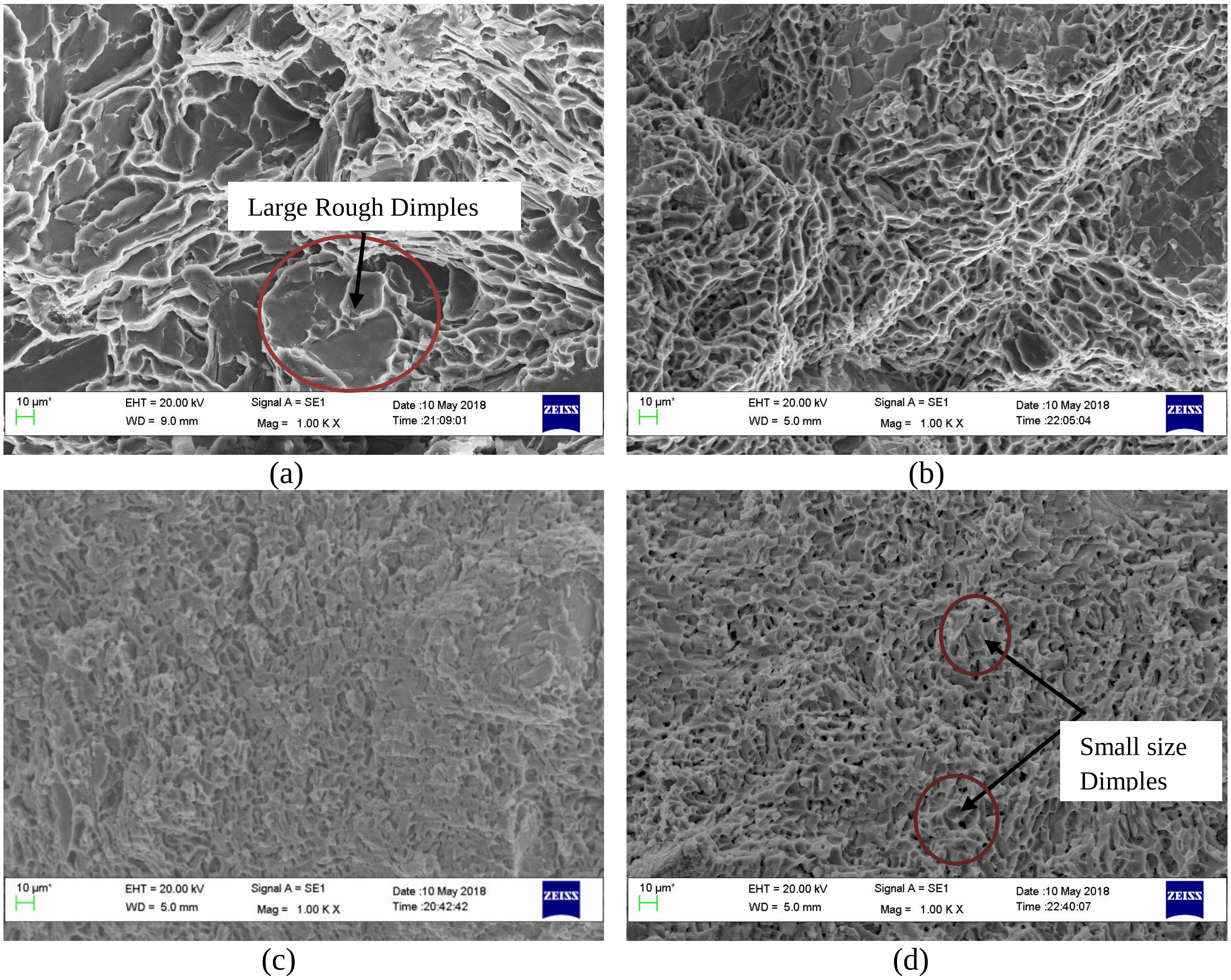

Figure 4 Fractographs of (a) as-received, (b) three pass, (c) six pass, and (d) nine pass specimens.

Figure 5 shows the alteration of hardness with number of passes. Continuous increment of hardness was observed with increment in number of passes, this is due to the introduction of residual stresses developed by strain hardening effect. The percentage change in the hardness of as-received material to nine pass material is 42.30 %.

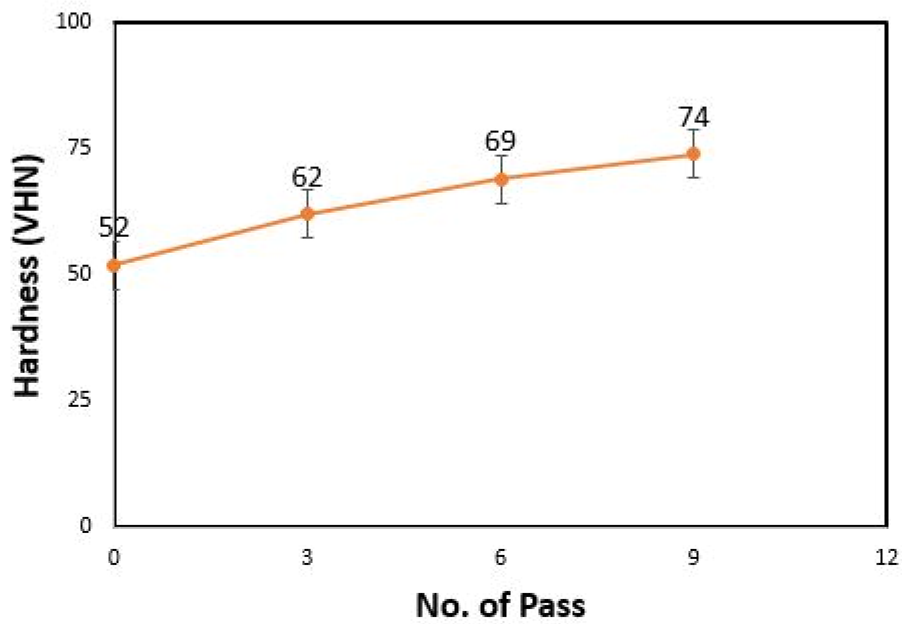

Figure 5 Variation of hardness with passes.

CONCLUSIONS

In this study multi-axial compression of LM6 Al alloy were performed and the effects of MAC were compared with as-received material. Based on this study, following conclusions are drawn.

1. Grain refinement of LM6 Al alloy is observed after nine MAC due to reduction in casting precipitate dendrites.
2. Ultimate tensile strength of LM6 Al alloy is expanded from 167 MPa to 270 MPa as the quantity of passes expanded from zero to nine. Increase in ultimate tensile strength is about 62%, it is due to grain refinement and work hardening.
3. Hardness value of the material increased from 52 VHN to 74 VHN as the passes increased from zero to nine.

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